Proposal for Dielectric Wakefield Acceleration Tests at NML

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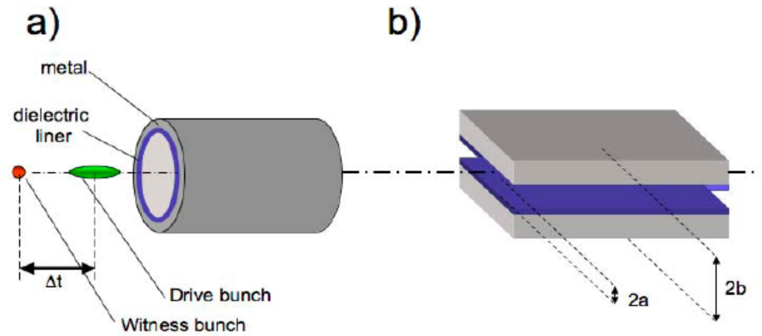
* GS working on beam dynamics supported by Los Alamos National Laboratory
& GS working on dielectric acceleration

Introduction

- Collinear beam-driven acceleration schemes are attractive
  - No laser is required
  - High power stored in drive beam



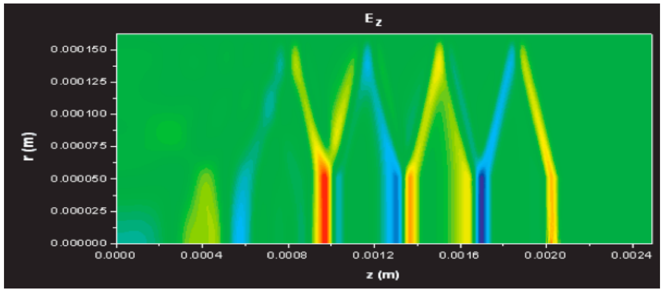
- Beam-driven dielectric wakefield accelerators (DWFAs) are simple to implement (e.g. compared to PWFA)
- Slab structure have several advantages
  - Mitigate transverse field (higher threshold for single bunch BBU)
  - Flat beams lessen space charge influence
- The main goals of our DTRA proposal are
  - experimentally test slab DWFA structures driven by beams with tailored emittance partition and current profile
  - develop fast numerical models of beam dynamics in DWFA

Uniqueness of NML for beam-driven acceleration tests

- Variable energy from ~40 (injector beamlines) to ~1 GeV,
  1st experiment maybe located in injector at 40 MeV and eventually relocated to the HE line
- High-repetition rate (3000 bunches over a 1-ms train),
  dynamical effect in structures (pulse heating, dielectric breakdown, multibunch dynamics?)
- L-band SCRF linac
  large rf wavelength accommodates drive witness pulses experiments,
- Photoinjector source
  low phase space volume, easy control of bunch train format
- Arbitrary emittance partition
  match the beam to the structure sizes,
- Tailored current profiles,
  enhancement of transformer ratio, drive+witness pulses,

Simulations of DWFA

- To date most simulations are carried out in eigensolvers (e.m. only) or PIC (e.m. + particles) codes,
- These detailed models require large computer and/or long execution time and make systematic optimization difficult.

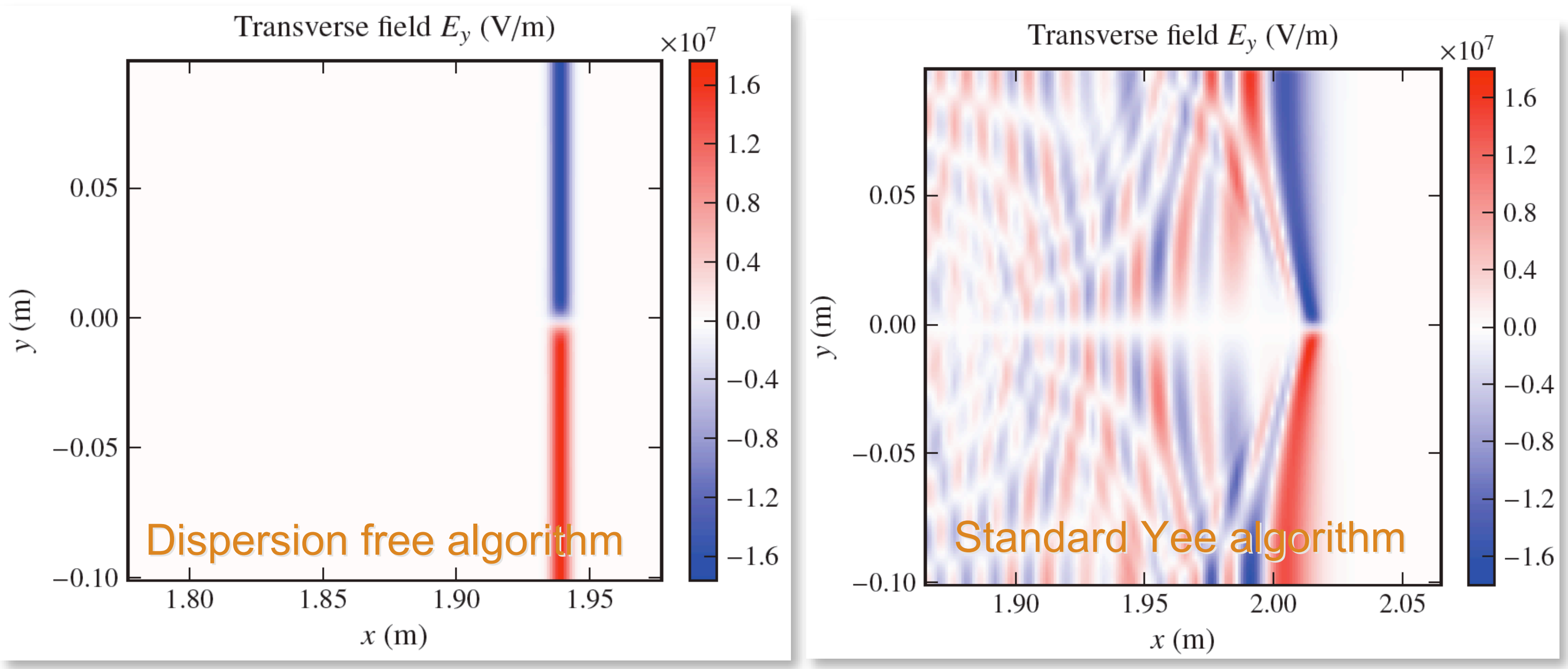


(OOPIC Pro simulations from UCLA)

- We plan on developing a non self-consistent model
  - PIC codes only run once to produce e.m. field generated by an electron bunch,
  - These e.m. fields will then be included non self-consistently in traditional beam dynamics program (Impact-T) to quickly model the electron beam dynamics in DWFA,
  - Our model will also include space charge effects which has to be taken into account at low energies (<100 MeV).
- With this model in hands we will be able to perform systematic optimization over a wide parameter space to design our experiment

Simulations of DWFA

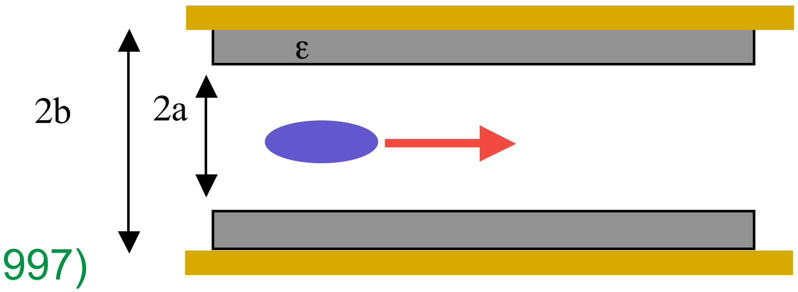
- Wakefield calculation will be performed with VORPAL,
- The code was recently upgraded with a unidirectional dispersion-free algorithm under a DOE/BES SBIR phase 1,
- A more user-friendly version is proposed as part of a DOE/BES SBIR phase 2 (NIU is a collaborative institution).



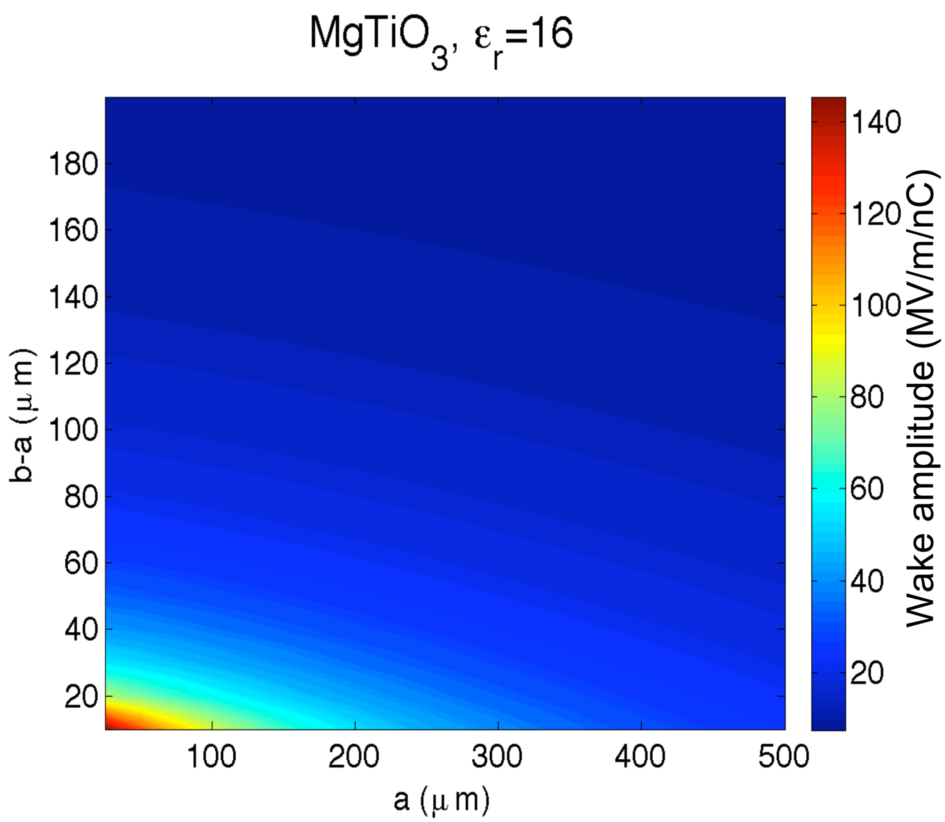
(these two plots were produced/provided by Ben Cowan Tech X Corp.)

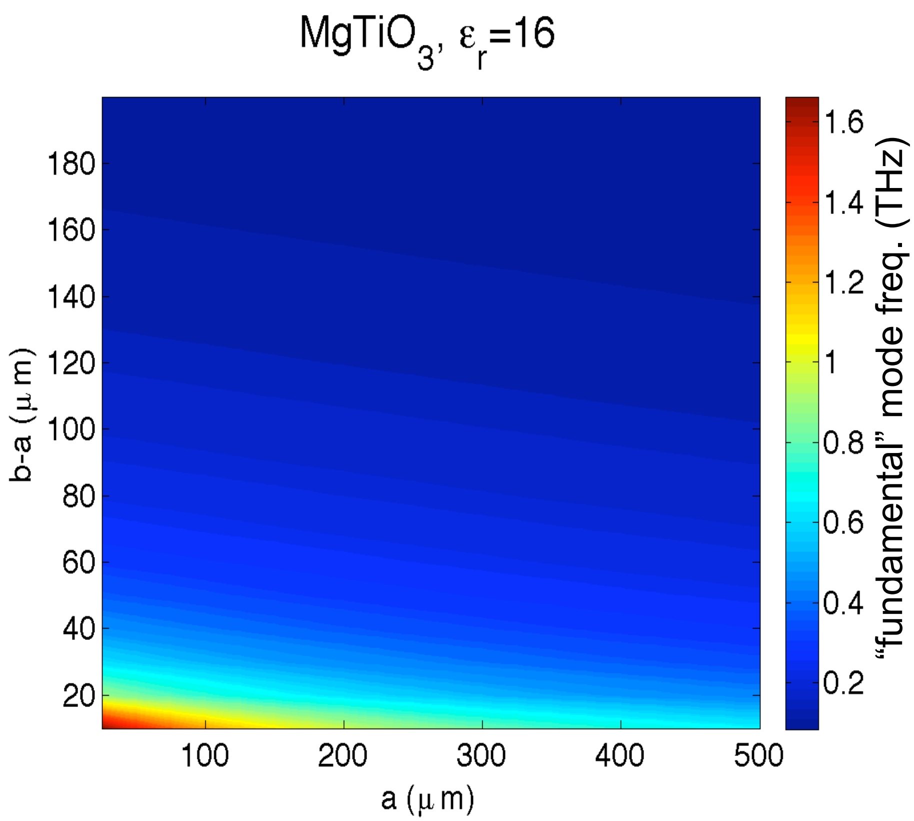
Estimated performances of DWFA at NML

- The anticipated NML beam could easily produce wake with peak fields >100 MV/m/nC .



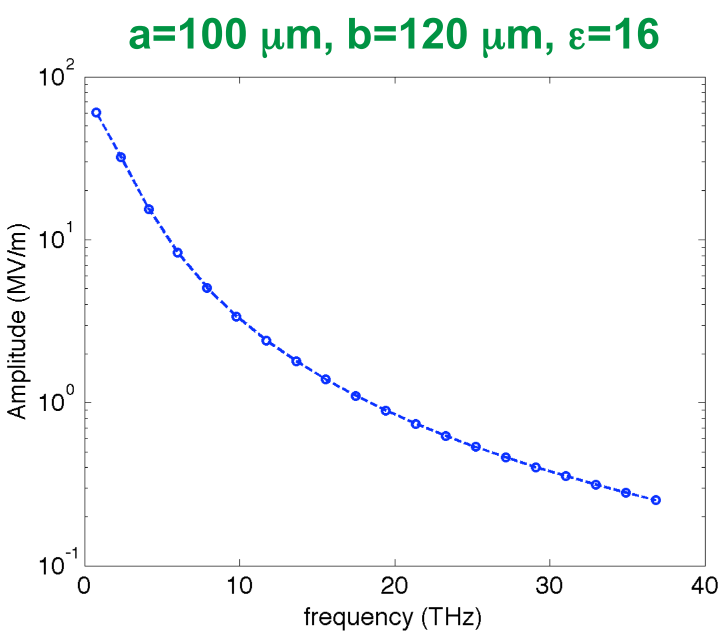
Using 1-D model from Tremaine et al, PRE 56, 7204 (1997)

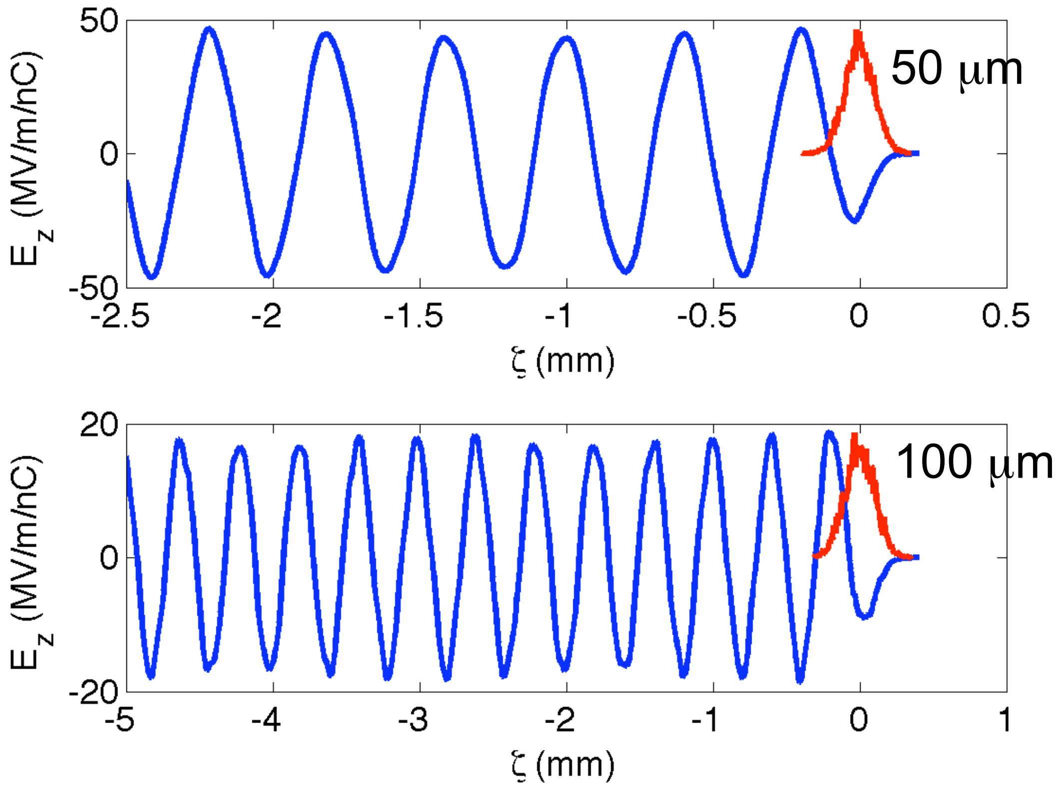




Estimated performance of DWFA at NML

- The structure parameters have to be optimized per the anticipated bunch parameters (especially bunch length)
- Another technique would be to produce a train of microbunches with the spacing matching the mode to be excited





Using 1-D model from Tremaine et al, PRE 56, 7204 (1997)

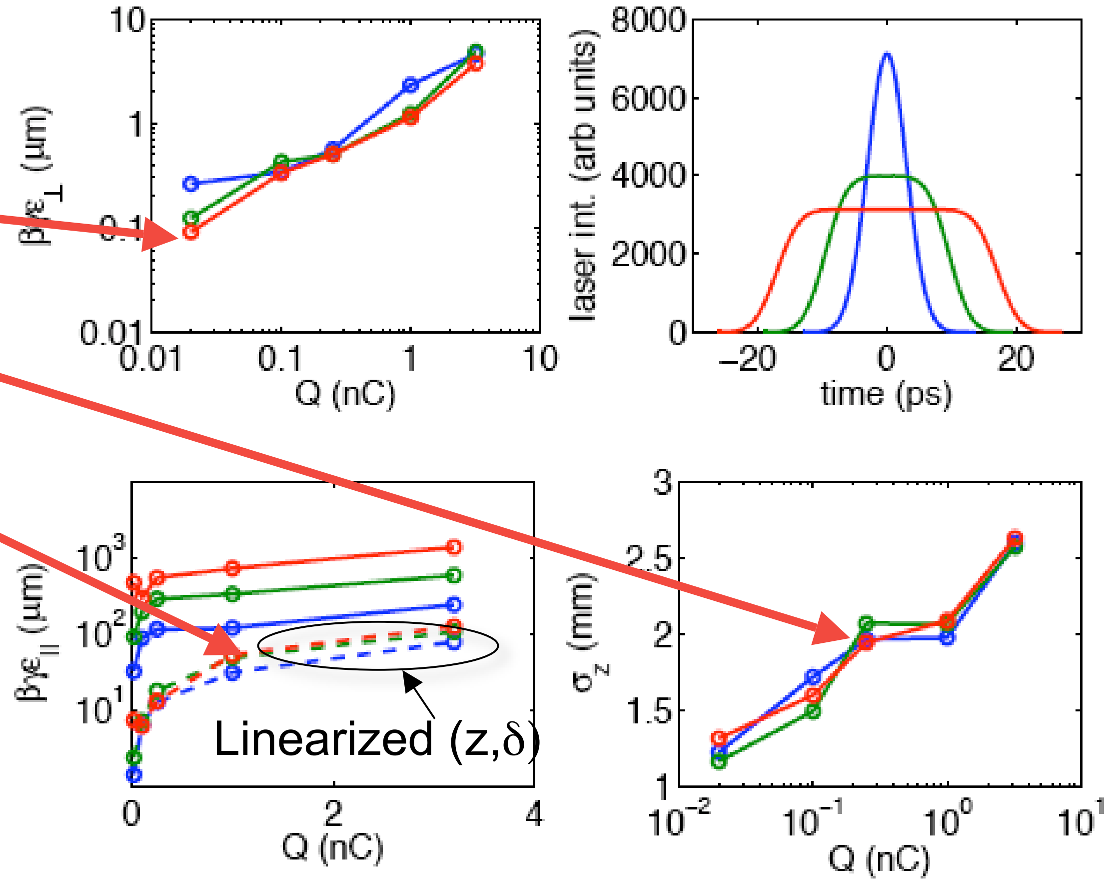
NML injector performances

- Optimization of NML Injector supports the production of bright electron beams
- Scaling for Gaussian laser distribution is

$$\varepsilon_\perp \approx 2.11 Q^{0.69}$$

$$\sigma_z \approx 2.18 Q^{0.13}$$

$$\varepsilon_z \approx 30.05 Q^{0.84}$$



- At 1 nC we estimate $\varepsilon_x/\varepsilon_y$=31/0.06 ~ 500 σ_δ=1.7x10^{-4} (40 MeV)

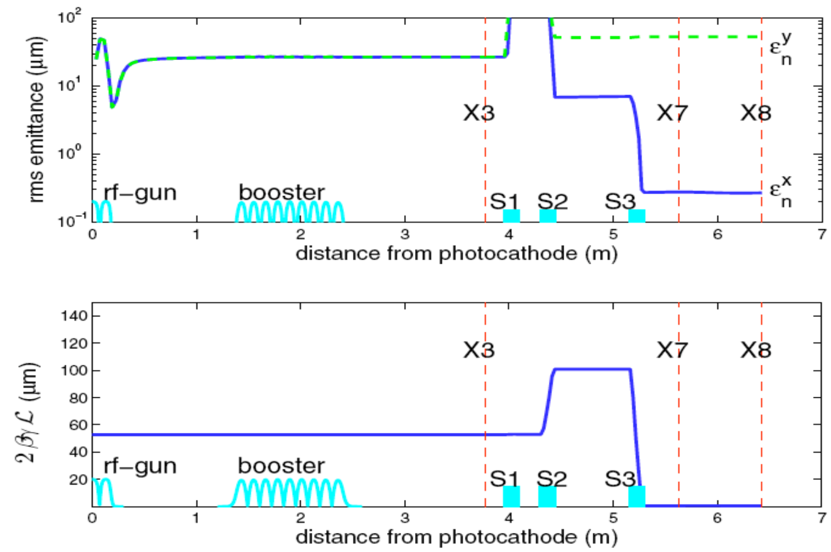
P. Piot et al., Proc. of IPAC10 (2010)

Flat beams at NML

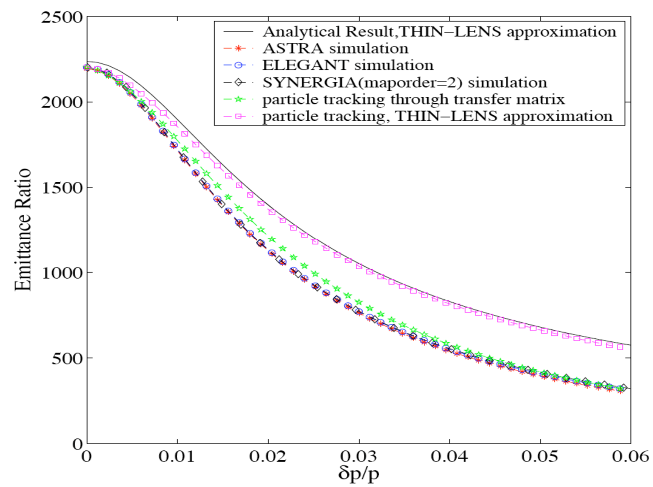
- NML incorporate a round-to-flat beam transformer
  A0 produced 40/0.4~100 emittance ratio

- Compressed flat beams
  the correlated energy spread required for compression
  ⇒ chromatic aberration

- Required correlated for full compression in BC1 (injec.) is $\delta p/p$~ 2%
  ⇒ emittance ratio of ~1000



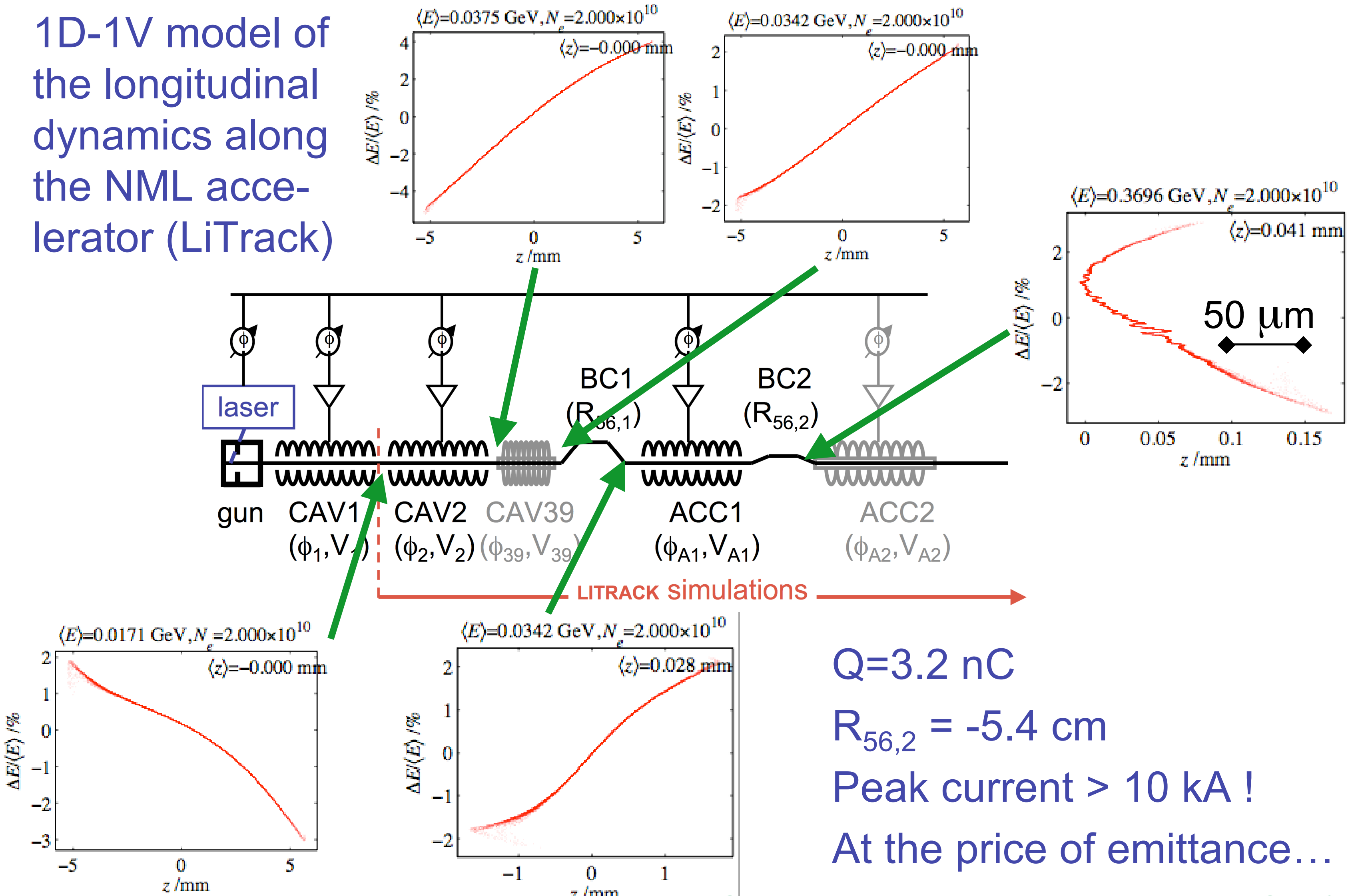
[P. Piot et al., PRSTAB 9 031001 (2006)]



[Y.-E Sun et al., Fermilab BeamDocs 1355v1 (2005)]

Bunch Compression

- 1D-1V model of the longitudinal dynamics along the NML accelerator (LiTrack)



Q=3.2 nC

$R_{56,2}$ = -5.4 cm

Peak current > 10 kA !

At the price of emittance…

[C. Prokop et al., Poster presented at IPAC10 (2010)]

Current profile tailoring

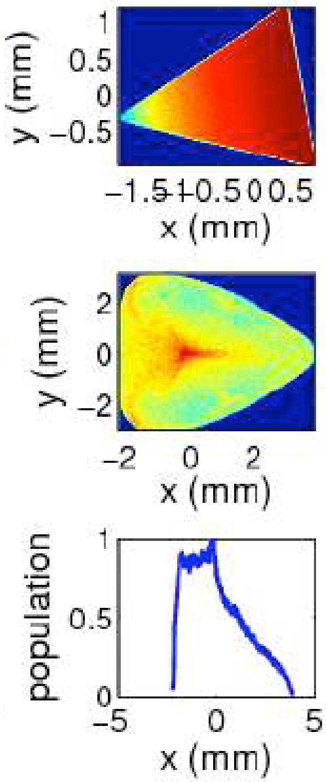
- Use of an emittance exchanger to tailor the current profile and enhance the transformer ratio

Beam upstream
EEX beamline

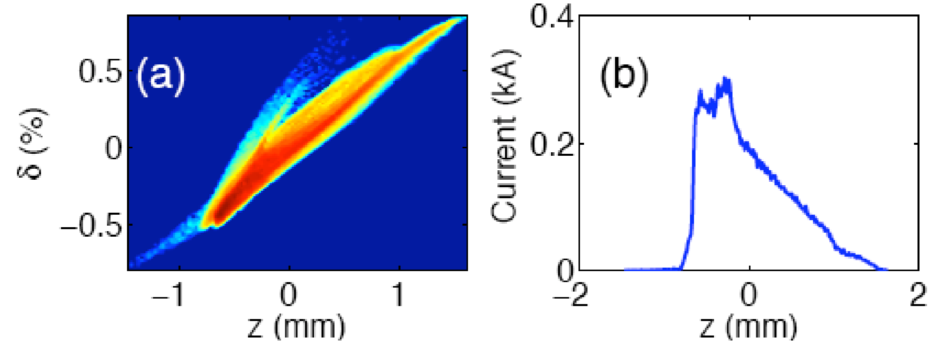
Laser spot
on cathode

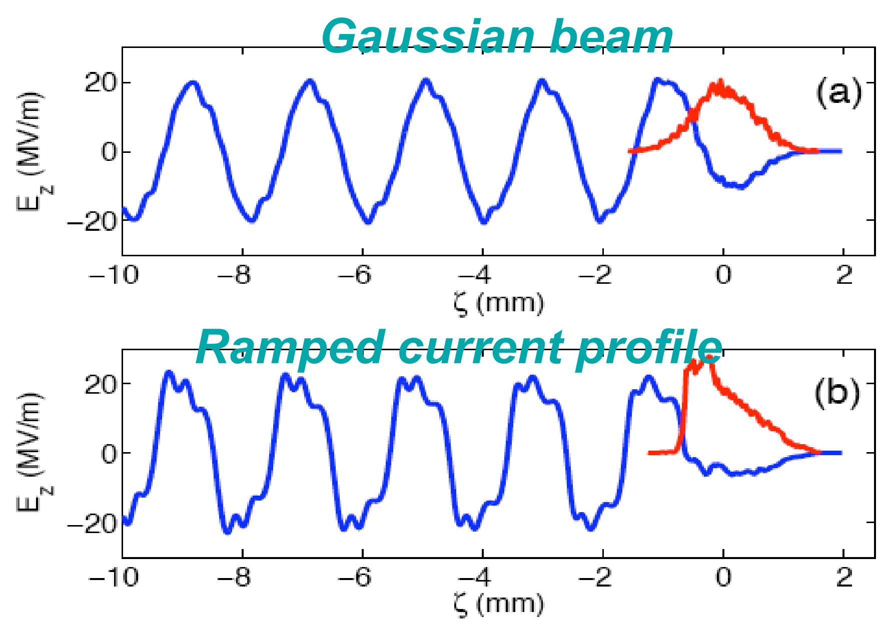
Electron
beam distrib.

Horizontal
profile



EEX
beamline

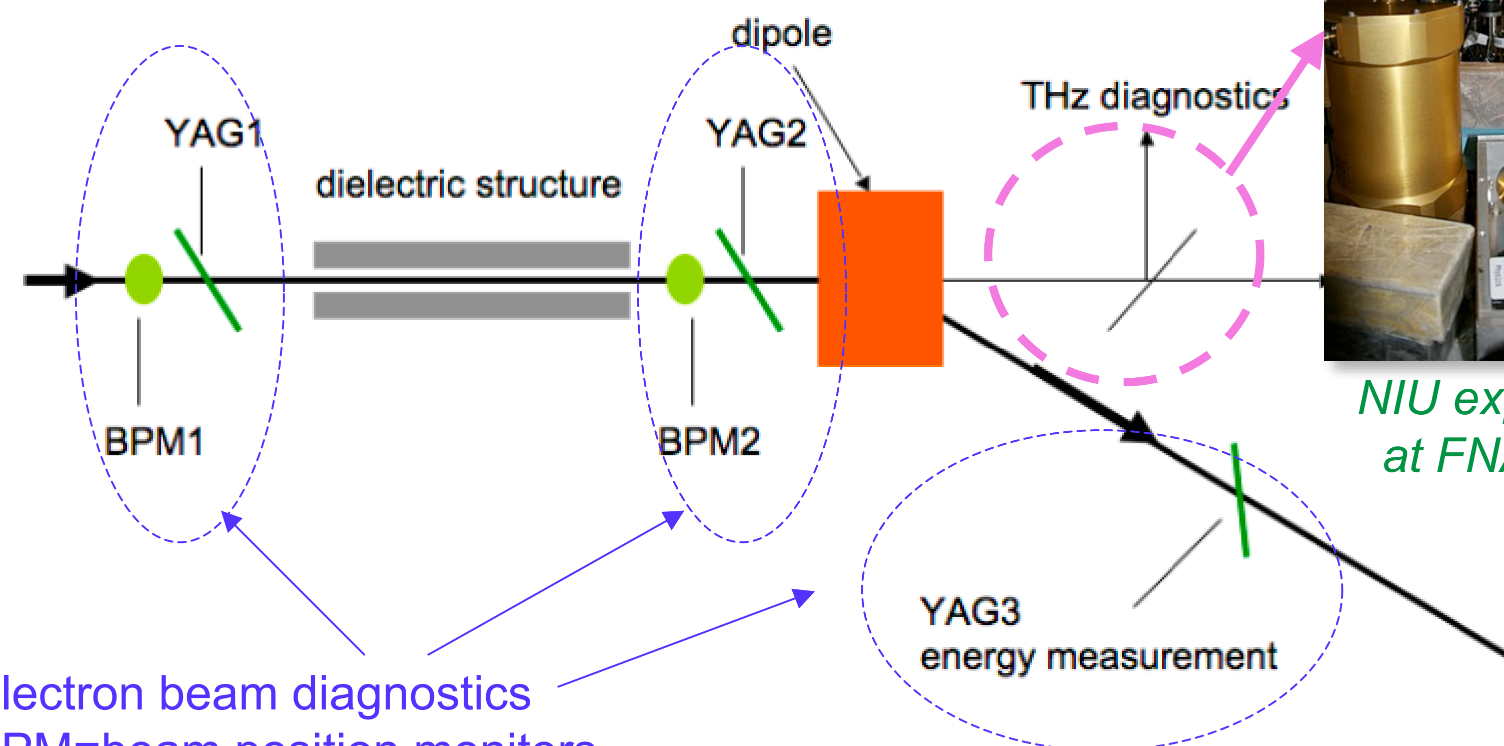


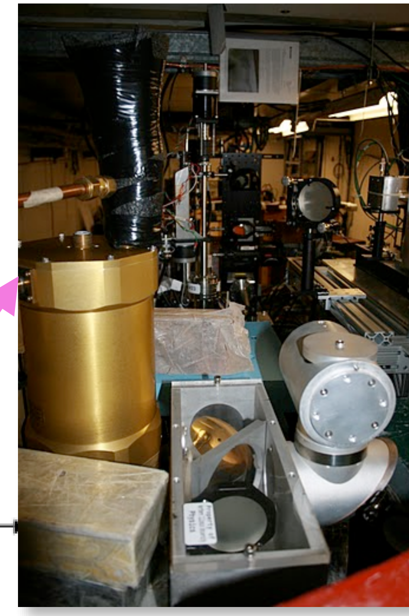


P. Piot, Proc. of AAC08 (2008)
P. Piot et al. ArXiV:1007.4499v1 (2010)

Proposed experimental setup

- Diagnostics
  - energy gain and loss
  - Cherenkov radiation



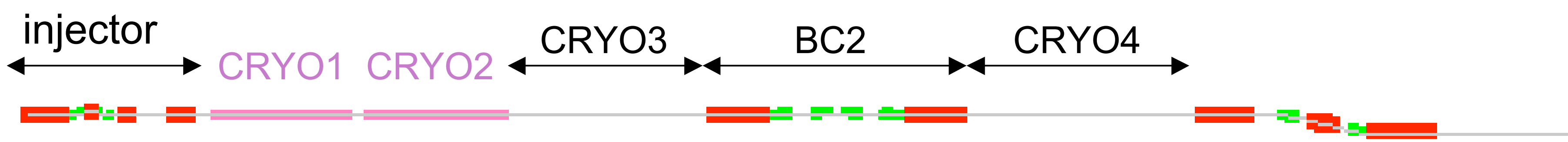


NIU experiment at FNAL's A0

Electron beam diagnostics
BPM=beam position monitors
YAG= Cs-doped Yttrium Aluminum Garnet or Optical transition radiation screens

Immediate plans

- Now developing a cathode-to-HE line model of the NML facility (ELEGANT, IMPACT-T/Z, ASTRA, CSRTRACK)
- Simulation will be “glue” together with GLUETRACK (DESY)
- Model for nominal beamline has been developed and we will investigate possible upgrade in support to AARD experiment (part of DOE renewal grant with NIU)
  - Two-stage compression
  - High-energy emittance exchanger at BC2



- DWFA experiment will most probably be staged
  - Phase 1: compressed flat beam at 40 MeV
  - Phase 2: tailored emittance partition and current profile using an emittance exchange

Summary

- NIU is currently preparing an experiment to test slab DWFA at NML
- NIU is collaborating with Tech-X to develop fast simulation tools to simulate the beam dynamics in DWFA

- The work involves intricate beam phase space manipulations (that still remains to be worked out in details):
  - Repartition emittance (produce flat compressed beam)
  - Exchange horizontal and longitudinal emittance to tailor the current profile

- The DWFA experiment is simple to implement and most of the work focus on the beam preparation (e.g. production of shaped current profile, witness + drive bunches)
- The techniques to be developed in support to our DWFA experiment will be **valuable and available** to other AARD experiments (PWFA, FEL's R&D, etc…)